



Upper Hudson River PCB Modeling System Hydrodynamic and Sediment Transport Models

Presented by
Li Zheng - Hydro/SedTran Technical Lead

Presented to
LimnoTech, Ann Arbor, MI

July 14, 2010

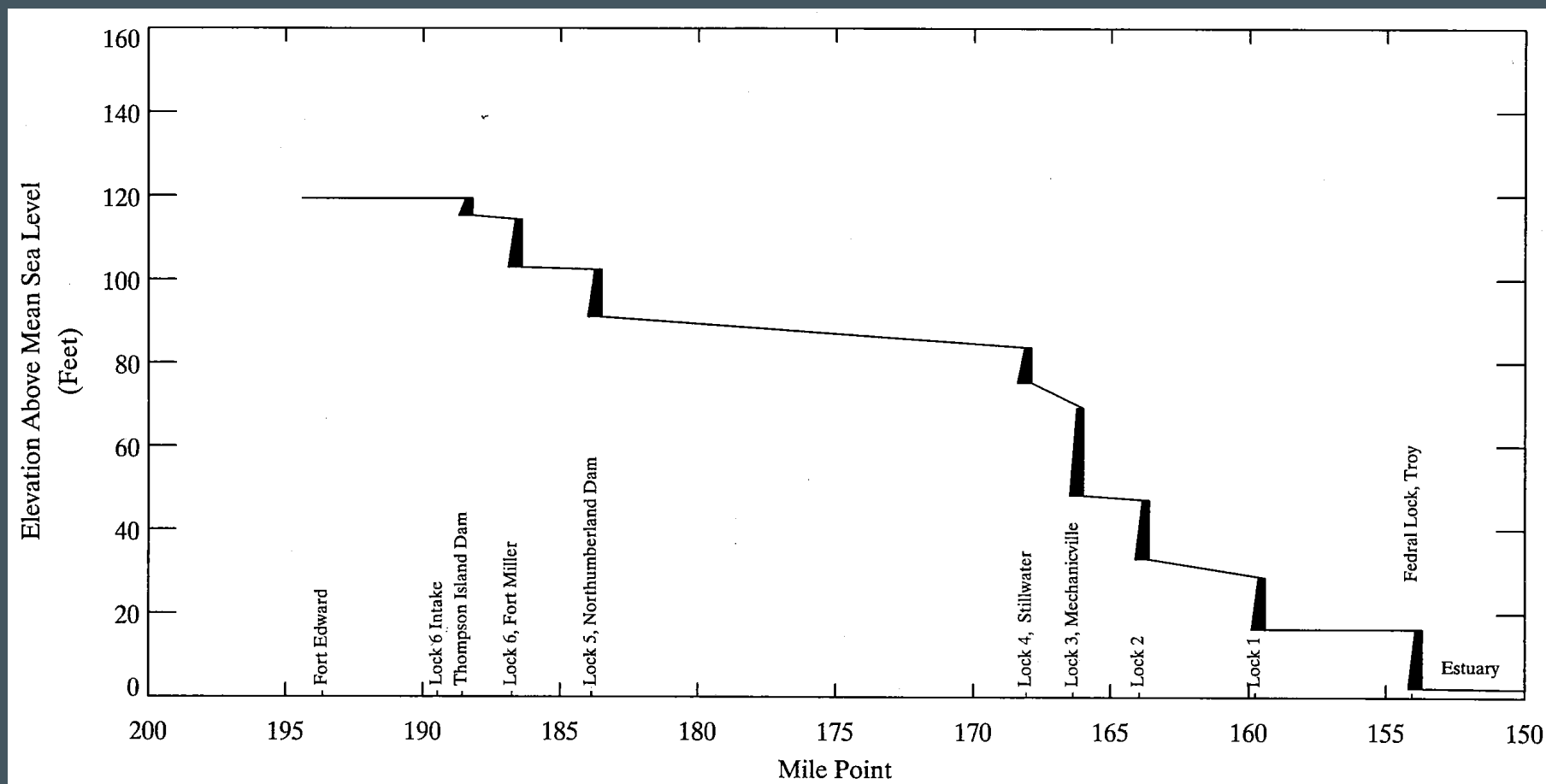
Hydrodynamic Model Overview

- Hydrodynamic model: EFDC
 - Modified and enhanced by Anchor QEA
- Model inputs
- Calibration and validation
- Summary

Hydrodynamic Model Inputs

- Geometry and bathymetry
- Boundary conditions
 - Inflows
 - Upstream boundary for Reach 8
 - USGS gauging station at Fort Edward
 - Tributaries: gauged or estimated
 - See Tables 4-3 and 4-4, *UHR Modeling System Report*
 - Stage height at dams
 - See Table 4-5, *UHR Modeling System Report*

Hydrodynamic Model Inputs



Hydrodynamic Model Calibration and Validation

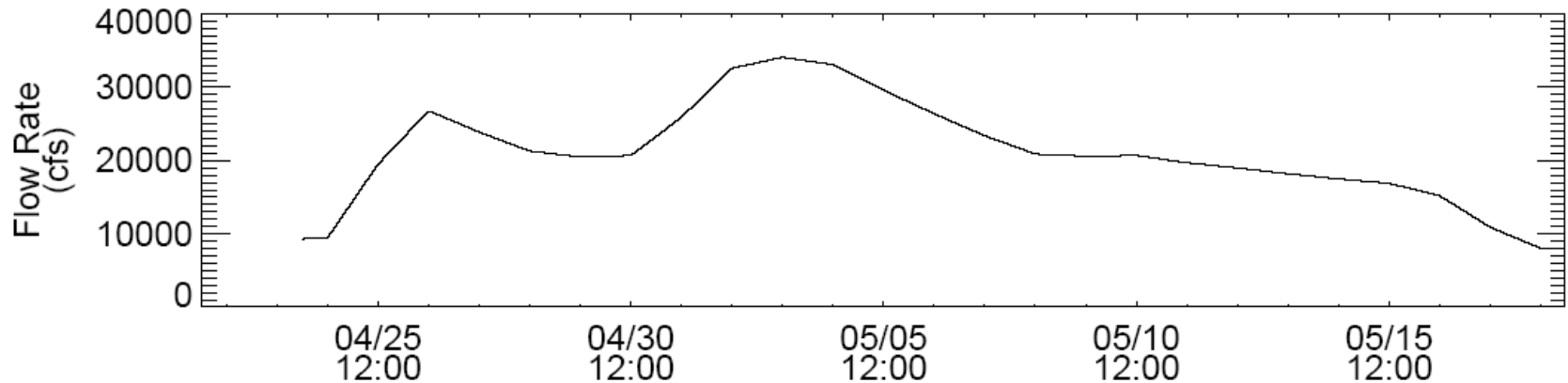
- Calibration
 - Stage height data collected during spring floods in 1983, 1993, and 1994
 - Adjustable parameter: effective bed roughness

Effective Bottom Roughness Height z_0 Used in the Hydrodynamic Calibration

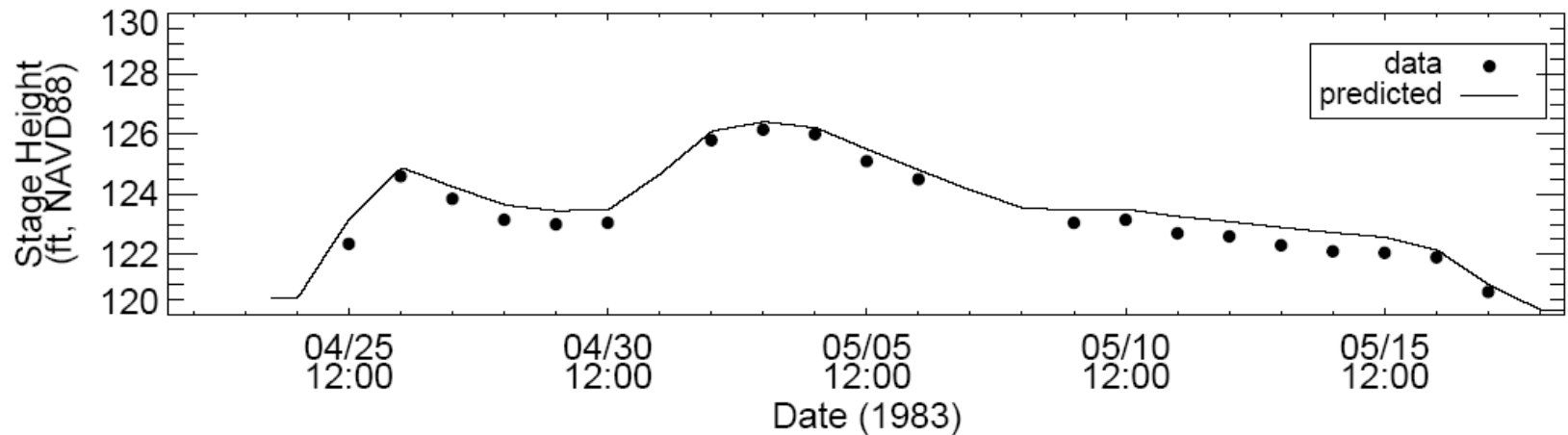
| Reach | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| z_0 (cm) | 1.0 | 5.0 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 |

- Validation
 - Current velocity and stage height data collected in 2004 and 2006
 - No parameters adjusted during validation

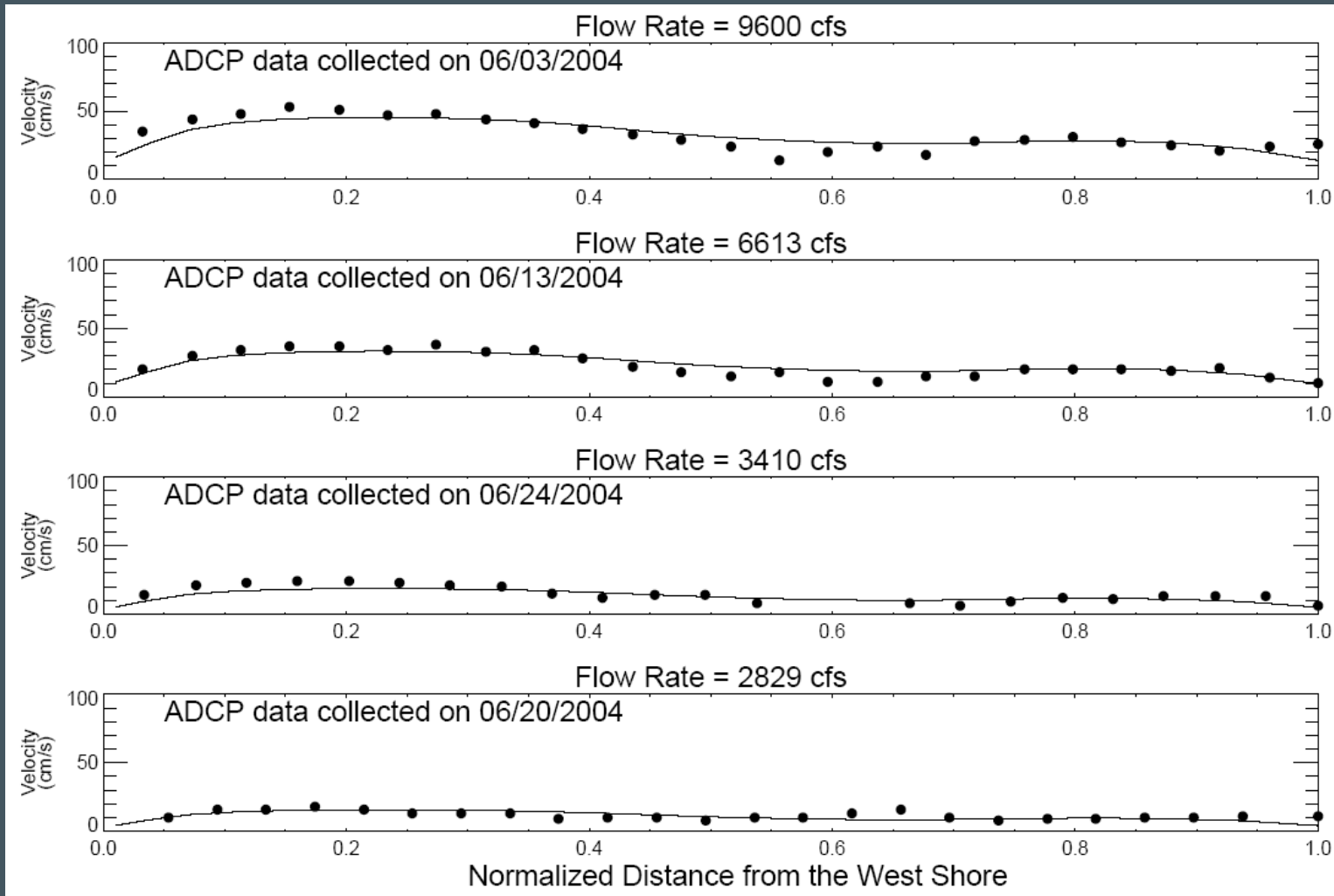
Hydrodynamic Model Calibration Results



1983 spring flood, TIP, Lock 7



Hydrodynamic Model Validation Results



SEDC5, RM 190 (near Griffin Island)

Hydrodynamic Model Summary

- Model adequately predicted stage height and velocity in UHR over a wide range of flow conditions
- Calibrated model was used to simulate UHR hydrodynamics for 34-year period (1977-2010)
- Hydrodynamic transport information was transferred to sediment transport model *via* “coupling files”

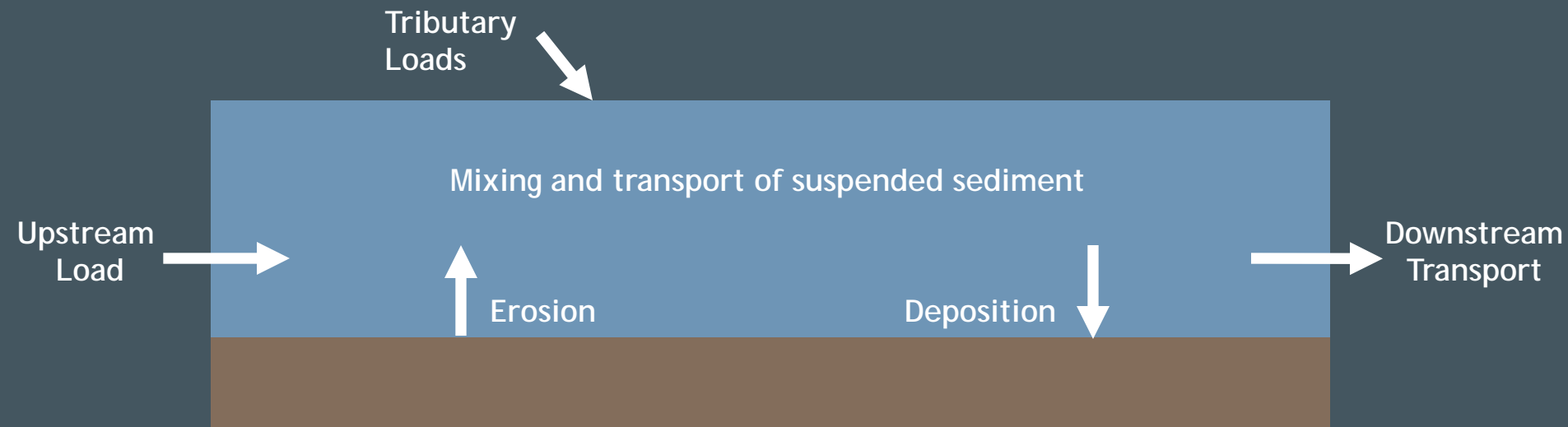
Sediment Transport Model Overview

- Description of model structure
- Development of model inputs
- Model calibration and validation
- Summary

Description of Model Structure

- Neglected bed load transport
 - Bed load transport has minimal effect on PCB transport
 - Bed load in the UHR is inhibited by the dams
 - Limited data to calibrate bed load in the UHR
 - Supported by bed type distributions upstream of dams
- Neglected feedback between hydrodynamics and sediment transport

Description of Model Structure



- Water column transport and bed shear stress information transferred from hydro model

Description of Model Structure:

Bed Shear Stress

- Skin friction shear stress

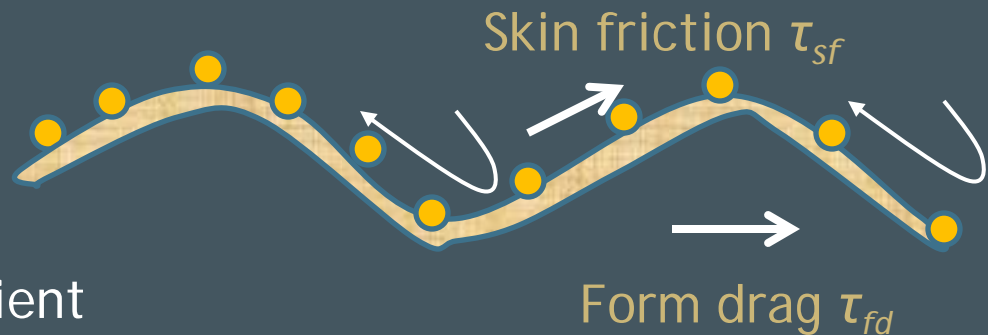
$$\tau_{sf} = \rho_w C_f q^2$$

$$C_f = \kappa^2 \ln^{-2}(11 h / k_s)$$

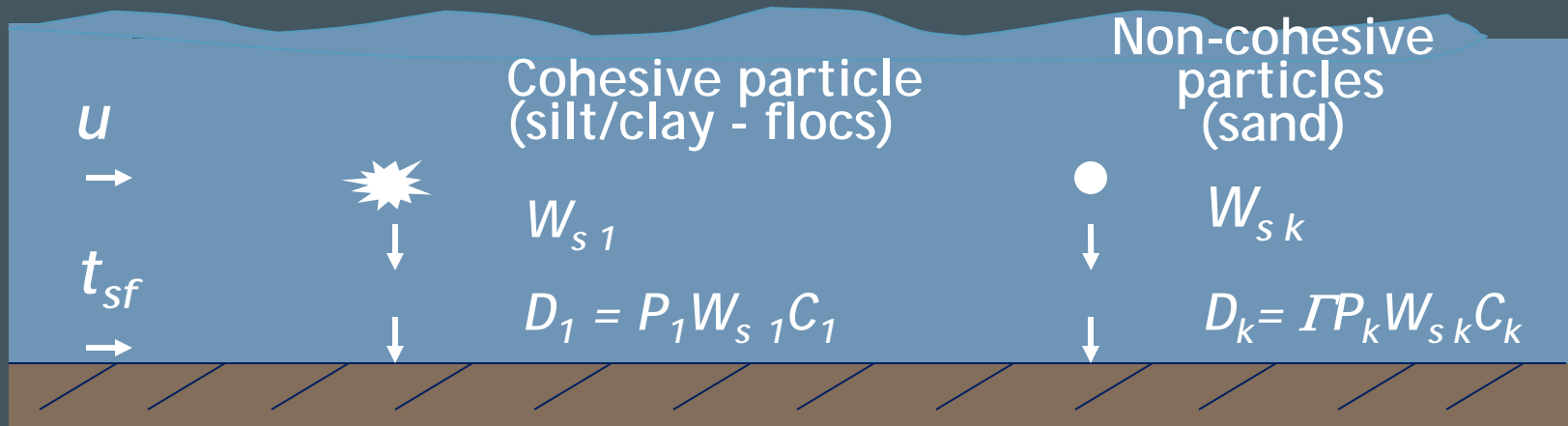
$$k_s = 2d_{90}$$

- Where:

- ρ_w = water density
- C_f = bed friction coefficient
- q = near-bed velocity
- h = water depth
- k_s = effective bed roughness
- d_{90} = 90th percentile particle diameter of bed sediment



Description of Model Structure: Deposition



Cohesive particles ($d \leq 62 \mu\text{m}$)

$$W_{s1} = f_1(C_1, t_{sf})$$

→ Burban et al. (1990) data

$$P_1 = g_1(t_{sf})$$

→ Partheniades probability of deposition

Non-cohesive particles ($d > 62 \mu\text{m}$)

$$W_{sk} = f_k(d_k)$$

→ Cheng (1997) settling speed

$$P_k = g_k(d_k, t_{sf})$$

→ Gessler probability of deposition

$$\Gamma = h(d_k, t_{sf})$$

→ stratification correction factor

$$d_k =$$

→ effective particle diameter

Description of Model Structure: Cohesive Bed Erosion

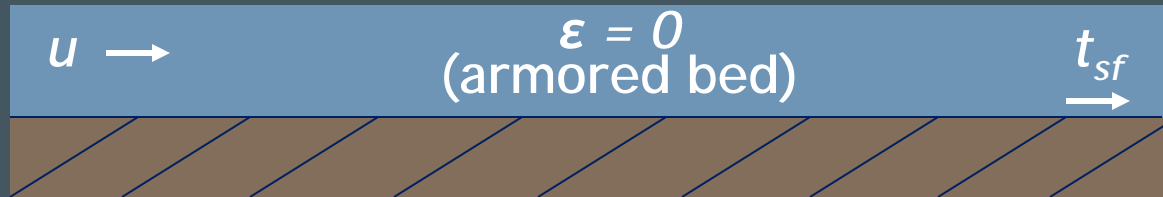
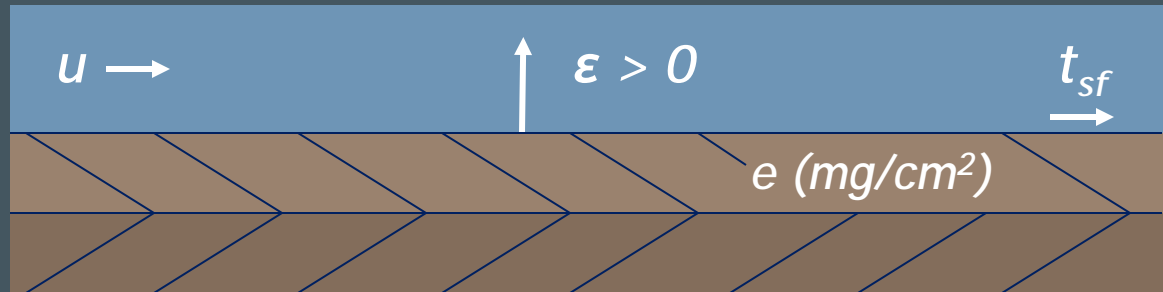
- Re-suspension potential

$$\varepsilon = \frac{a_0}{T_d^N} \left(\frac{\tau_b - \tau_{cr}}{\tau_{cr}} \right)^n,$$

$$\tau_b \geq \tau_{cr}$$

- Where:
 - ε = net mass of resuspended sediment per unit surface area
 - A_0 = site-specific constant
 - T_d = time after deposition in days
 - N, n = exponents dependent upon the deposition environment
 - T_b = skin friction shear stress (dynes/cm²)
 - T_{cr} = effective critical shear stress (dynes/cm²)

Description of Model Structure: Cohesive Bed Erosion



- SEDZL algorithm (QEA 1999, Ziegler *et al.* 2000)
- Resuspension potential (ε) depends upon τ_{sf} and bed properties
- Resuspension parameter values determined from field data
- 3D bed model tracks spatial and temporal changes in properties

Description of Model Structure: Non-cohesive Bed Erosion

- Erosion flux in non-armoring bed (Van Rijn [1984])

$$E_{na,k} = -W_{s,k} (C_{a,k} - C_{eq}), \quad C_{a,k} < C_{eq}$$

- Erosion flux from an armoring bed

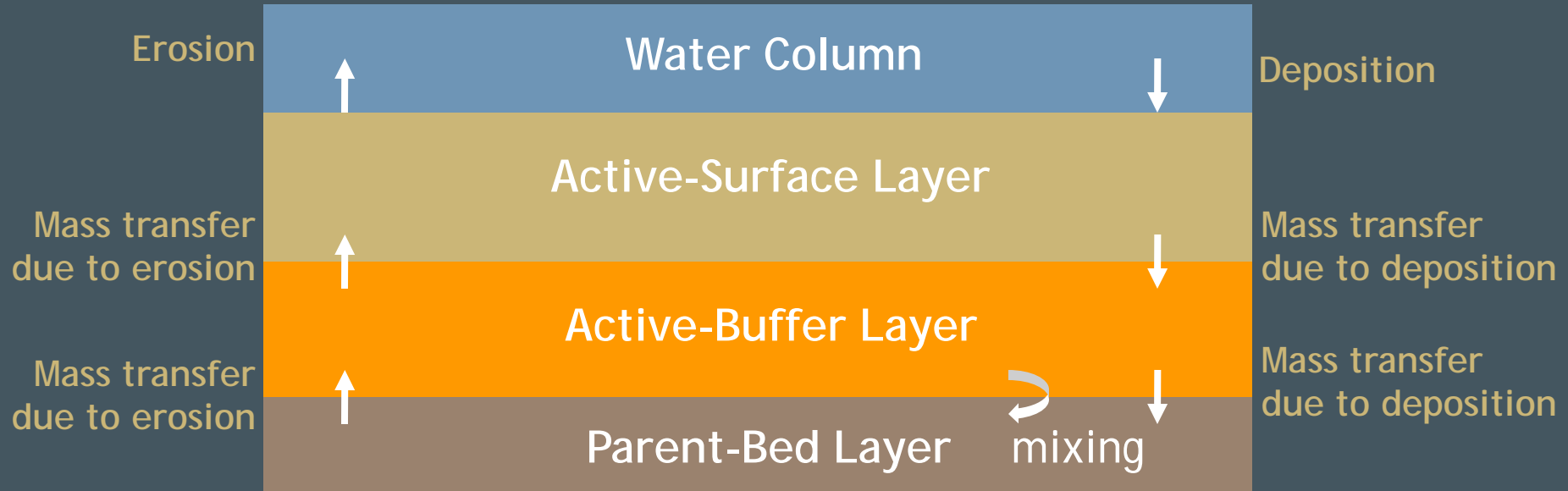
$$E_k = f_{AS,k} P_{sus,k} S_k E_{na,k}$$

- Where:
 - $f_{AS,k}$ = fraction of class k sediment in the active-surface layer of the non-cohesive bed
 - $P_{sus,k}$ = probability of suspension for size class k
 - S_k = particle-shielding factor for size class k

Bed Structure

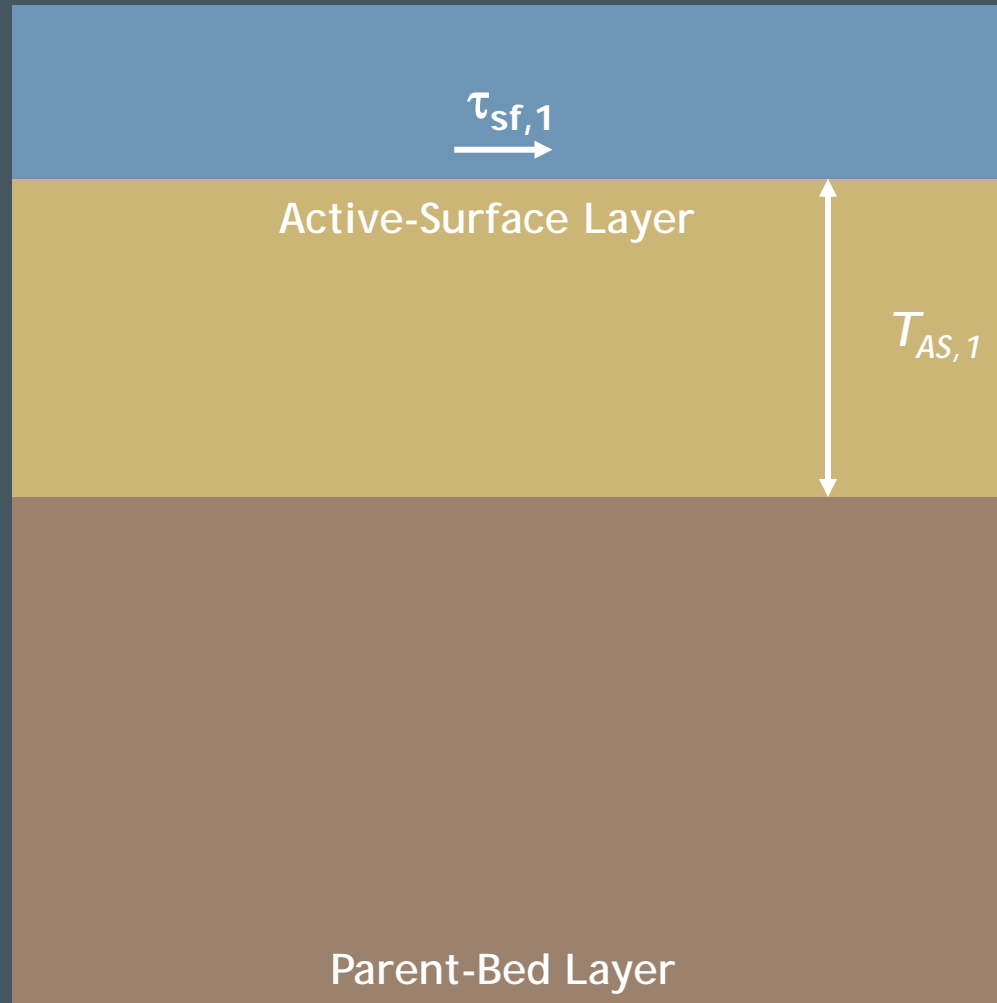


Description of Model Structure: Non-Cohesive Bed Erosion

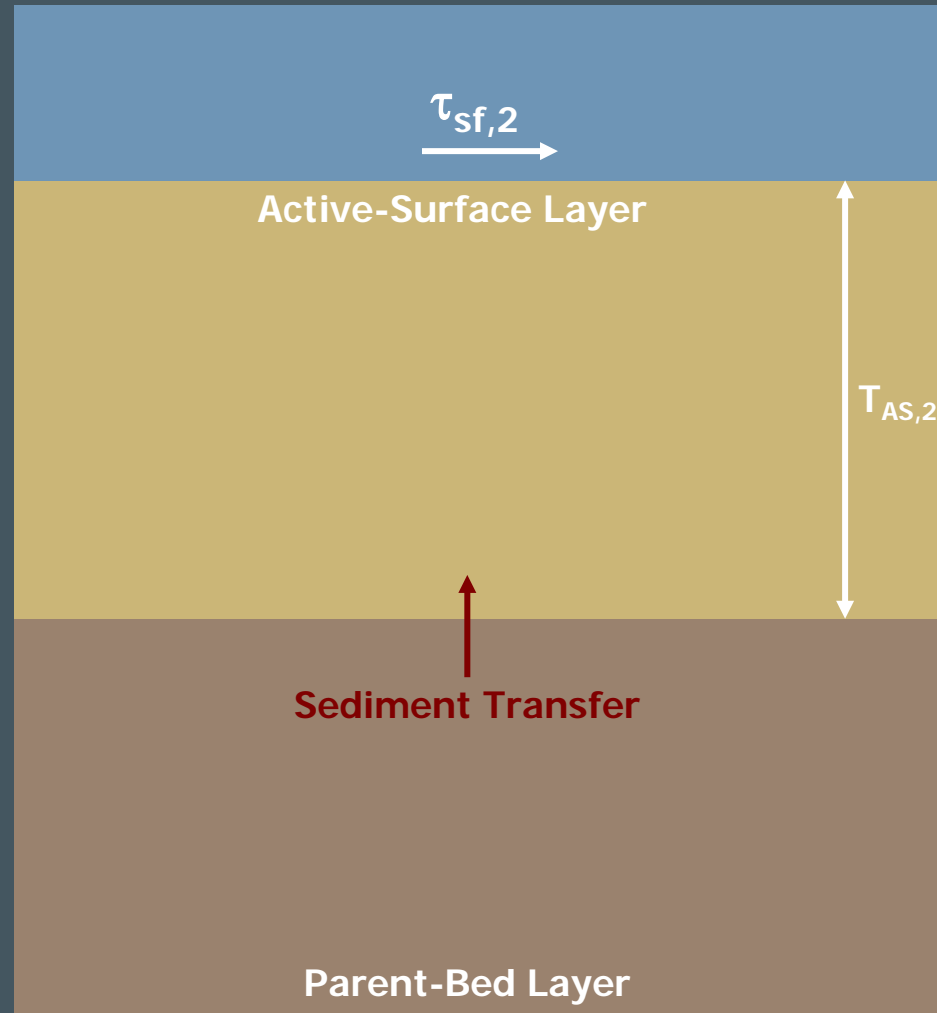


- 3D bed model: active (surface + buffer) layer and parent bed
- Active-surface layer thicken. ~ bed shear stress and grain size dist.
- Mixing process ~ de-armoring of bed during post-flood

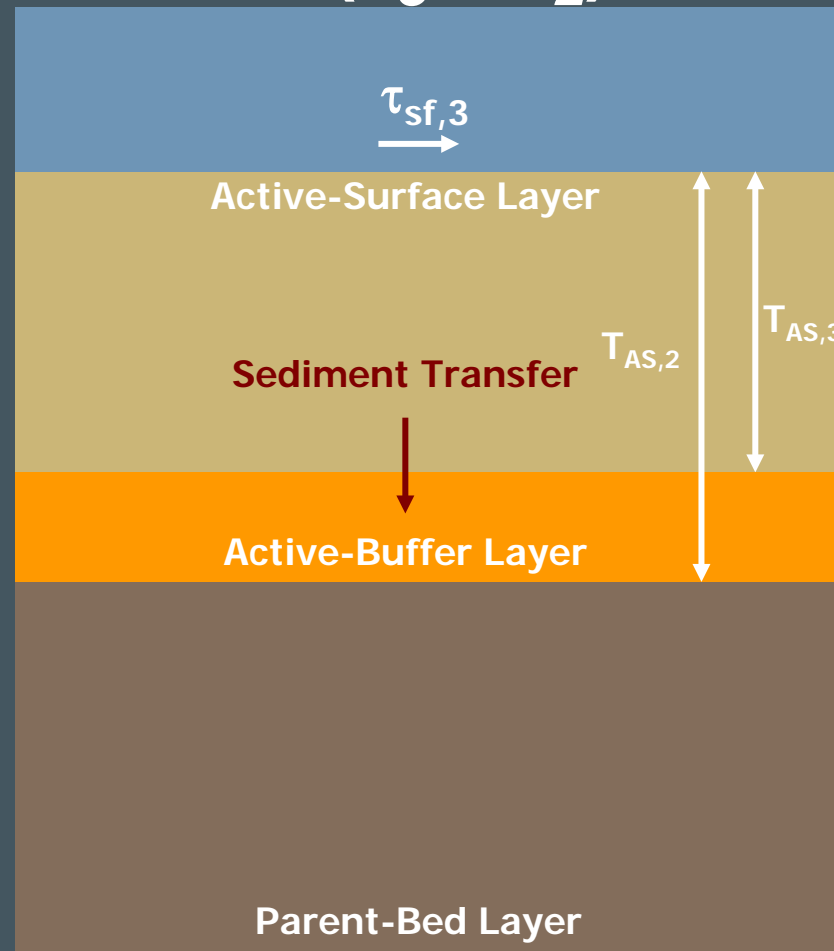
Initial Structure of Bed With No Active-Buffer Layer at Time = t_1



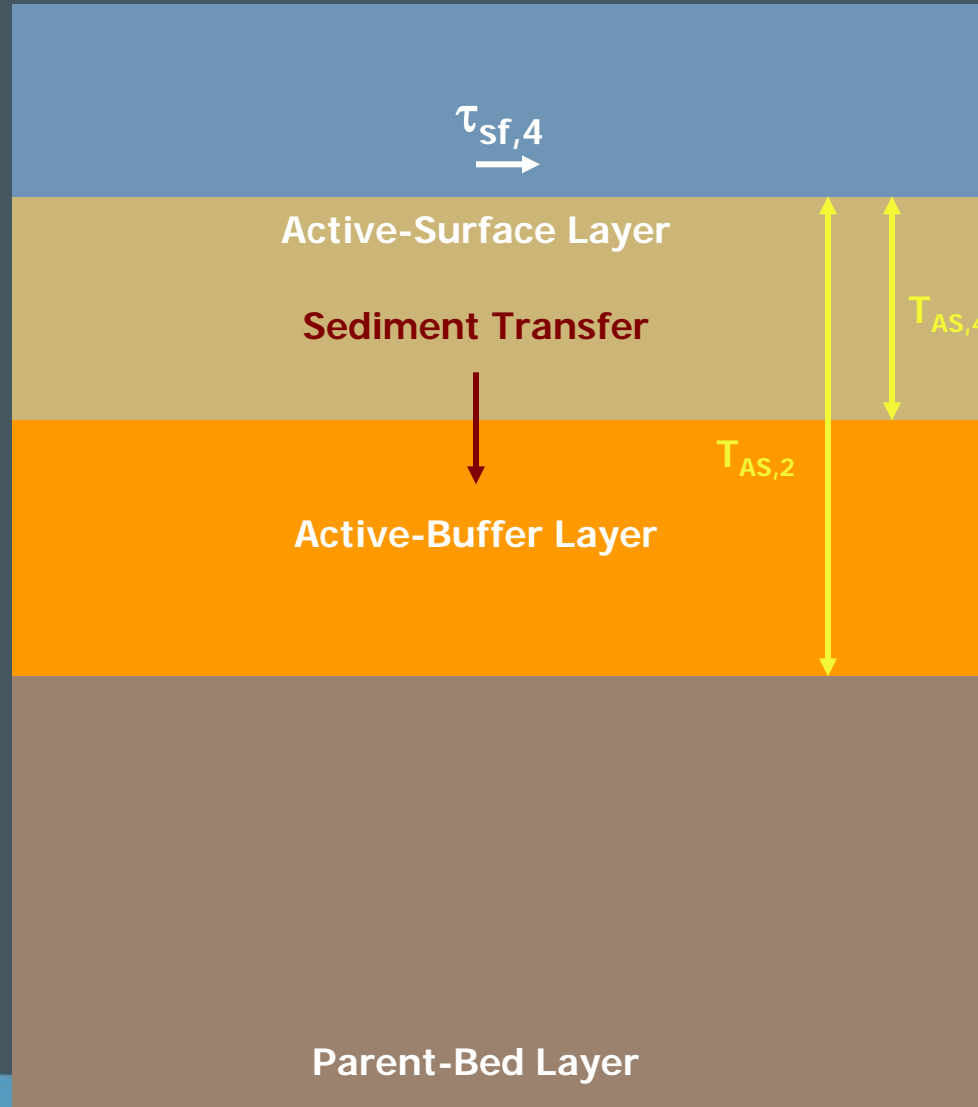
Active-Surface Layer Thickness Increases as Shear Stress Increases ($\tau_2 > \tau_1$) at Time = t_2



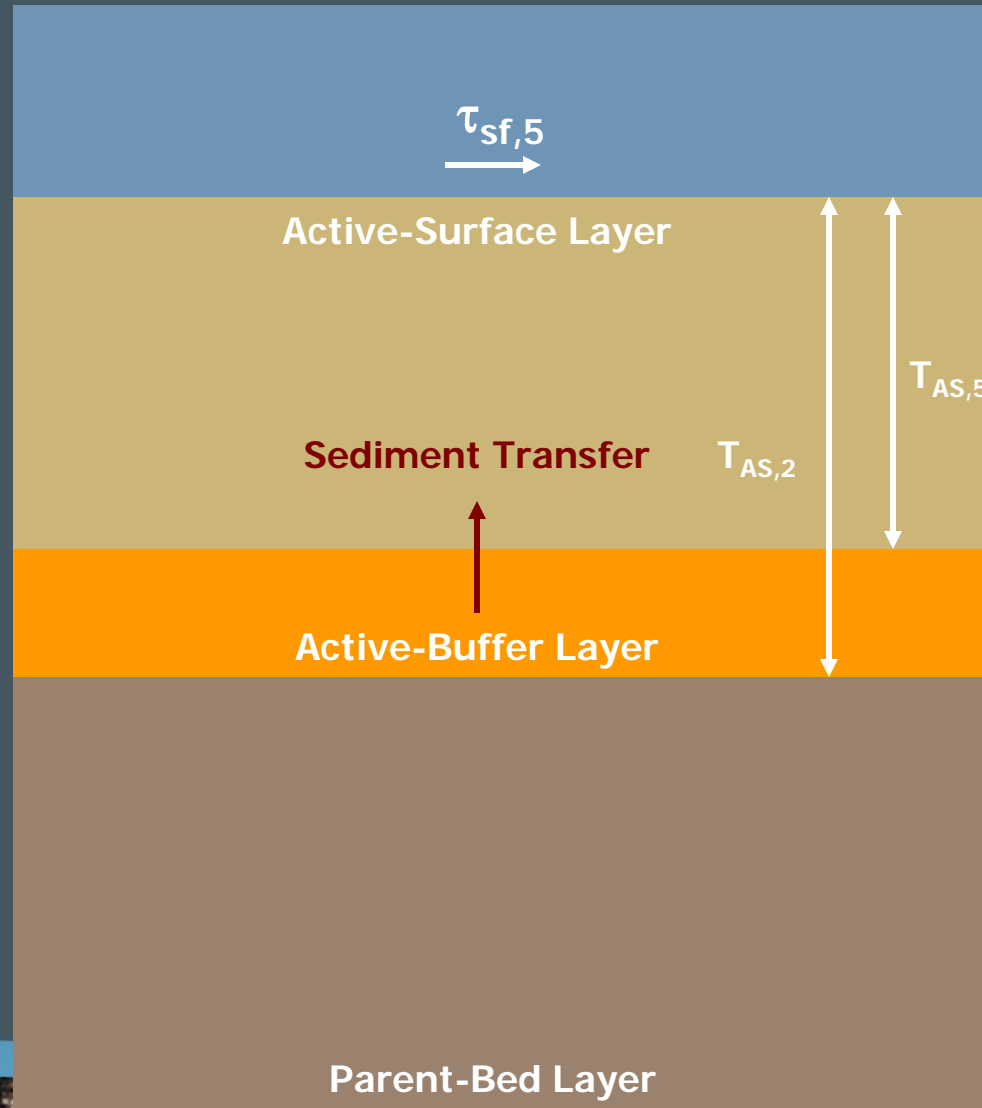
Active-surface Layer Thickness Decreases and Active-buffer Layer is Created as Shear Stress Decreases ($\tau_3 < \tau_2$) at Time = t_3



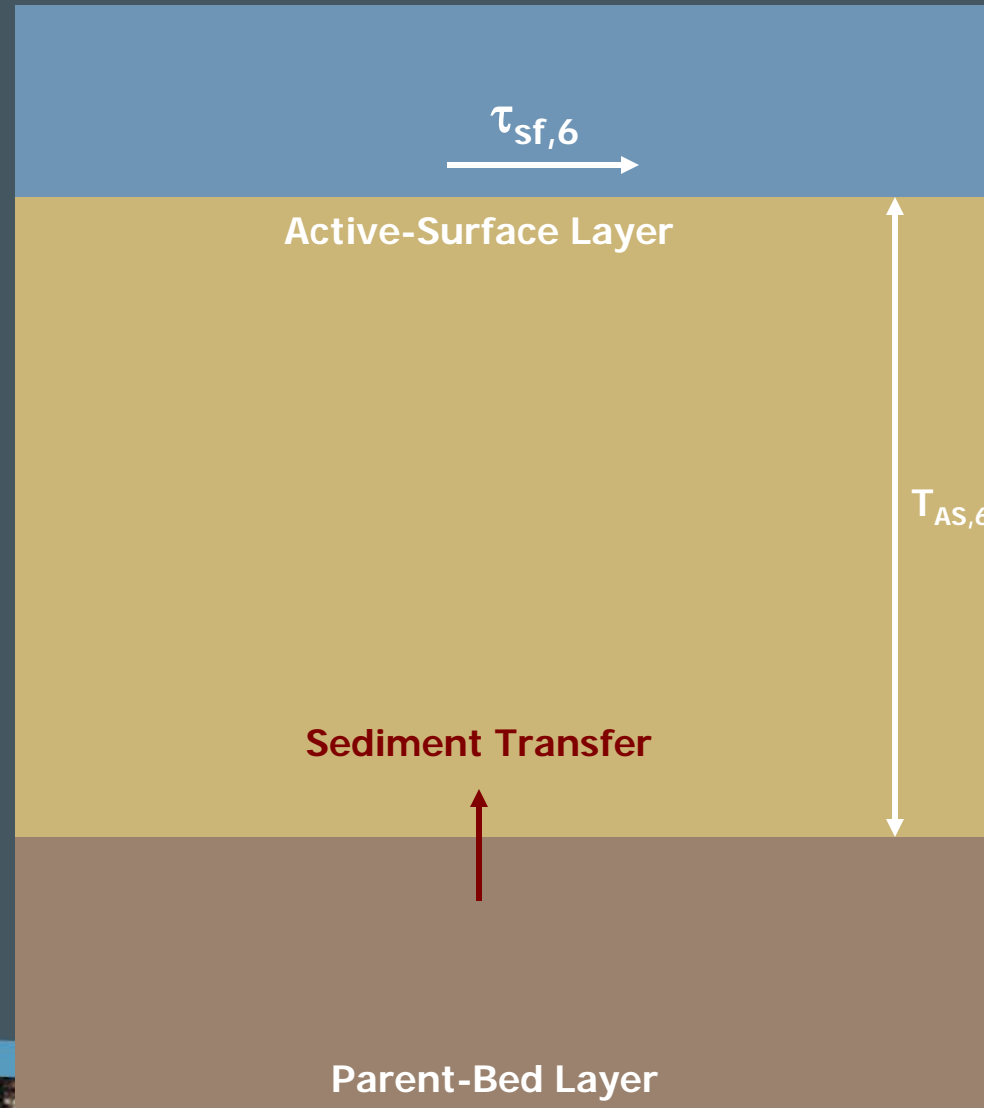
Active-surface Layer Thickness Decreases and Active-Buffer Layer Thickness Increases as Shear Stress Continues to Decrease ($\tau_4 < \tau_3$) at Time = t_4



Active-surface Layer Thickness Increases and Active-buffer Layer Thickness Decreases as Shear Stress Increases ($\tau_5 > \tau_4$) at Time = t_5



Active-surface Layer Thickness Increases and Active-buffer Layer is Destroyed as Shear Stress Increases ($\tau_6 > \tau_5$, $\tau_6 > \tau_2$) at Time = t_6

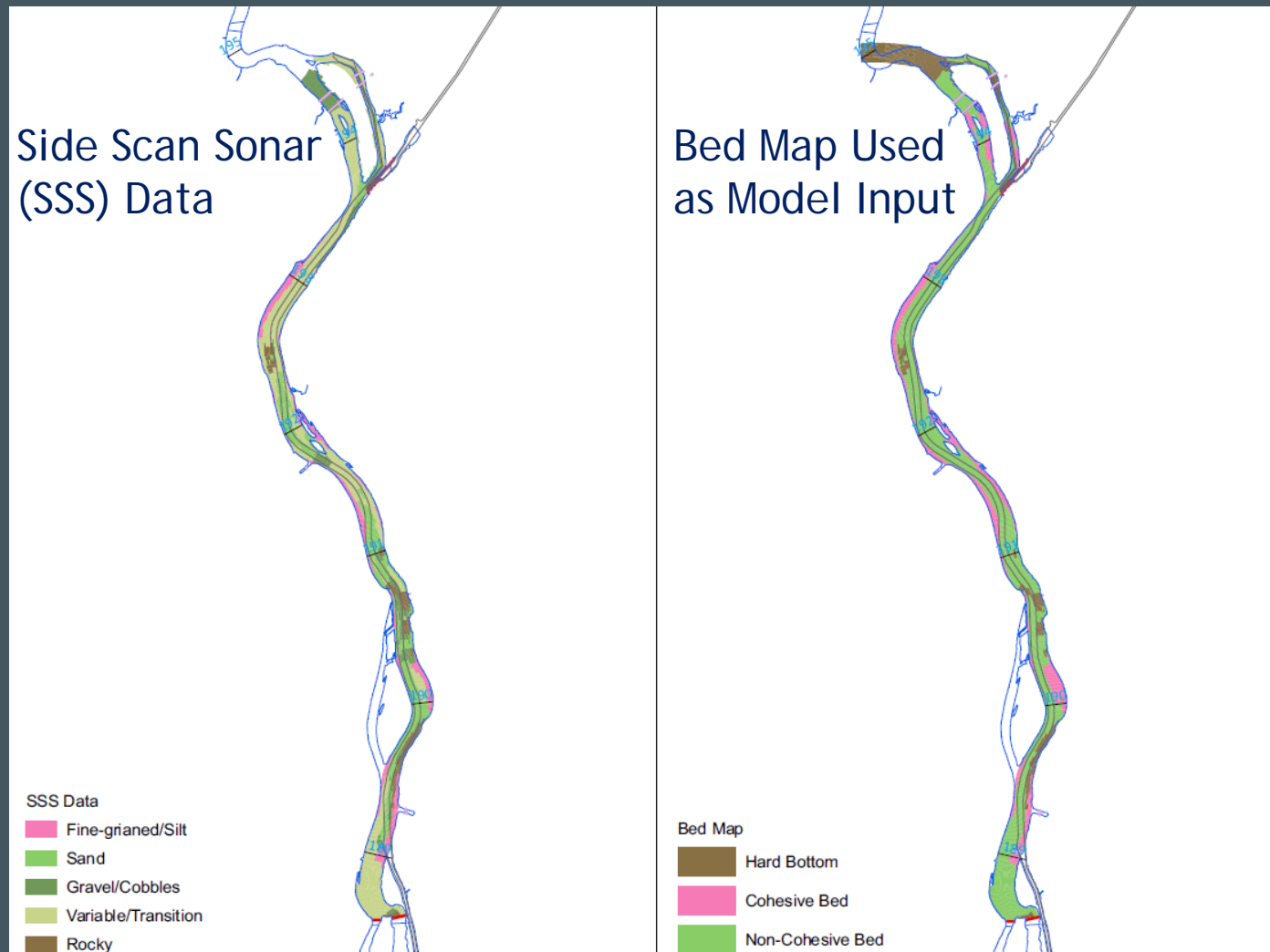


Development of Model Inputs

- Four sediment size classes
 - Class 1: clay/silt ($<62\ \mu\text{m}$)
 - Class 2: fine sand ($62 - 250\ \mu\text{m}$)
 - Class 3: medium/coarse sand ($250 - 2,000\ \mu\text{m}$)
 - Class 4: gravel ($>2,000\ \mu\text{m}$)
- Each size class represented by an effective particle diameter
 - Effective particle diameters for Classes 2 and 3 were calibration parameters
 - Effective particle diameters for Class 4 were determined from grain size distribution data

Development of Model Inputs: Bed Maps

See Figures 5-2 through 5-9 and Table 5-2; UHR Modeling System Report



Development of Model Inputs: Bed Properties

- Dry (bulk) density
 - Different values for cohesive and non-cohesive bed areas within a specific reach
- Initial sediment bed composition
 - Cohesive bed: spatially constant
 - Non-cohesive bed: spatially variable
- Erosion rate properties for cohesive bed
 - Determined from shaker study data
 - Reach 8: spatially variable
 - Reaches 1-7: spatially constant within a reach

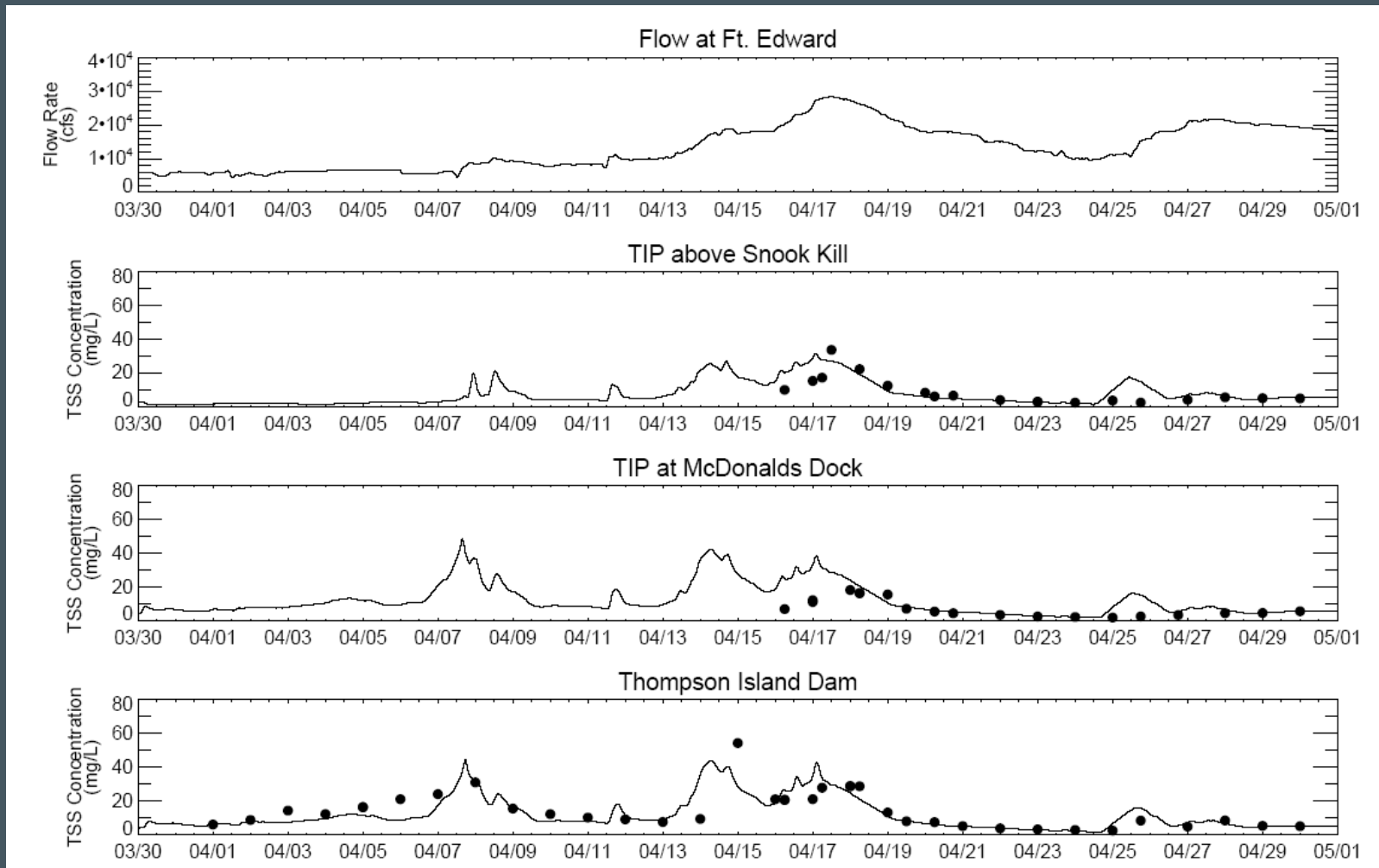
Development of Model Inputs: Boundary Conditions

- Magnitude of incoming sediment loads
 - Upstream boundary at FE: combination of data and rating curve (incorporated hysteresis effect during a flood)
 - Tributaries: rating curve estimates
- Composition of incoming sediment loads
 - Based on limited data
 - Class 1 (clay/silt) content: 75%
 - Class 2 (fine sand) content: 25% (except Moses Kill and direct drainage)

Sediment Transport Model Calibration

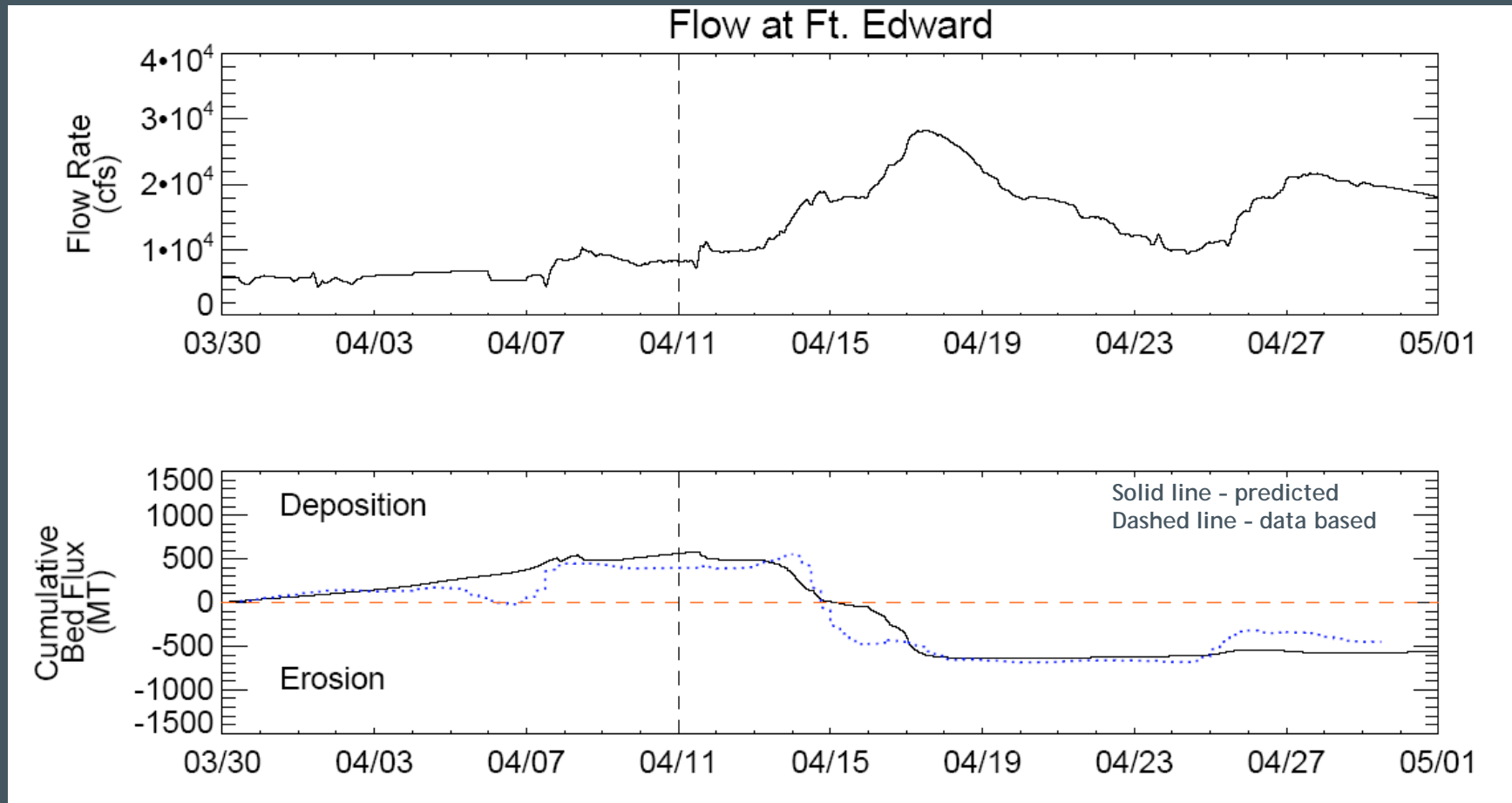
- Used data collected during spring flood in 1994
 - TSS concentrations
 - Solids mass balance
- Used iterative approach which combined high-flow event and long-term simulations
- Calibration parameters (Table 5-9, Report)
 - Effective diameters of Classes 2 and 3
 - Exponent in active-surface layer thickness equation
 - Active-buffer layer decay rate

Sediment Transport Model Calibration



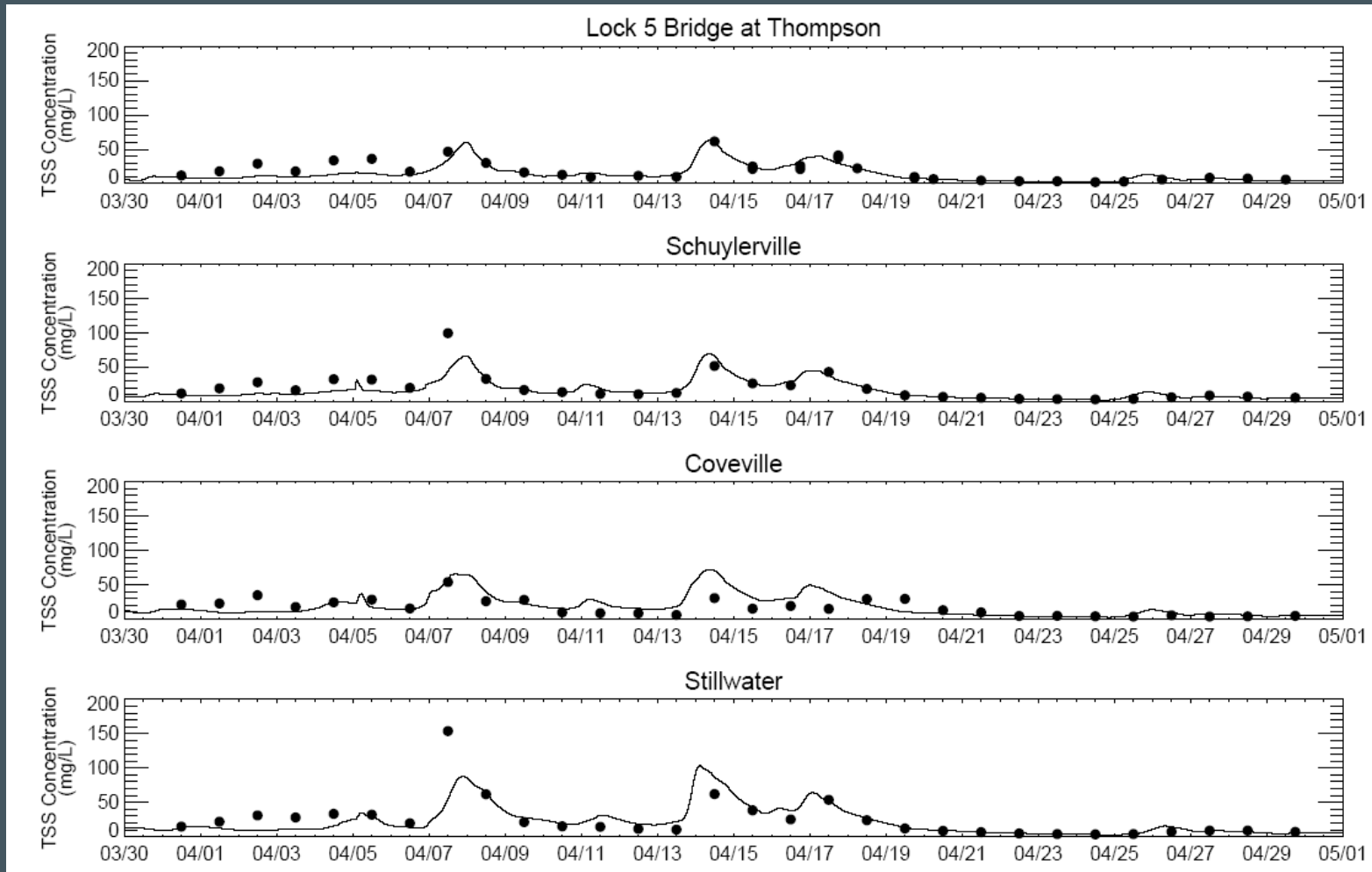
March 30 - April 29, 1994

Sediment Transport Model Calibration: Mass Balance Results



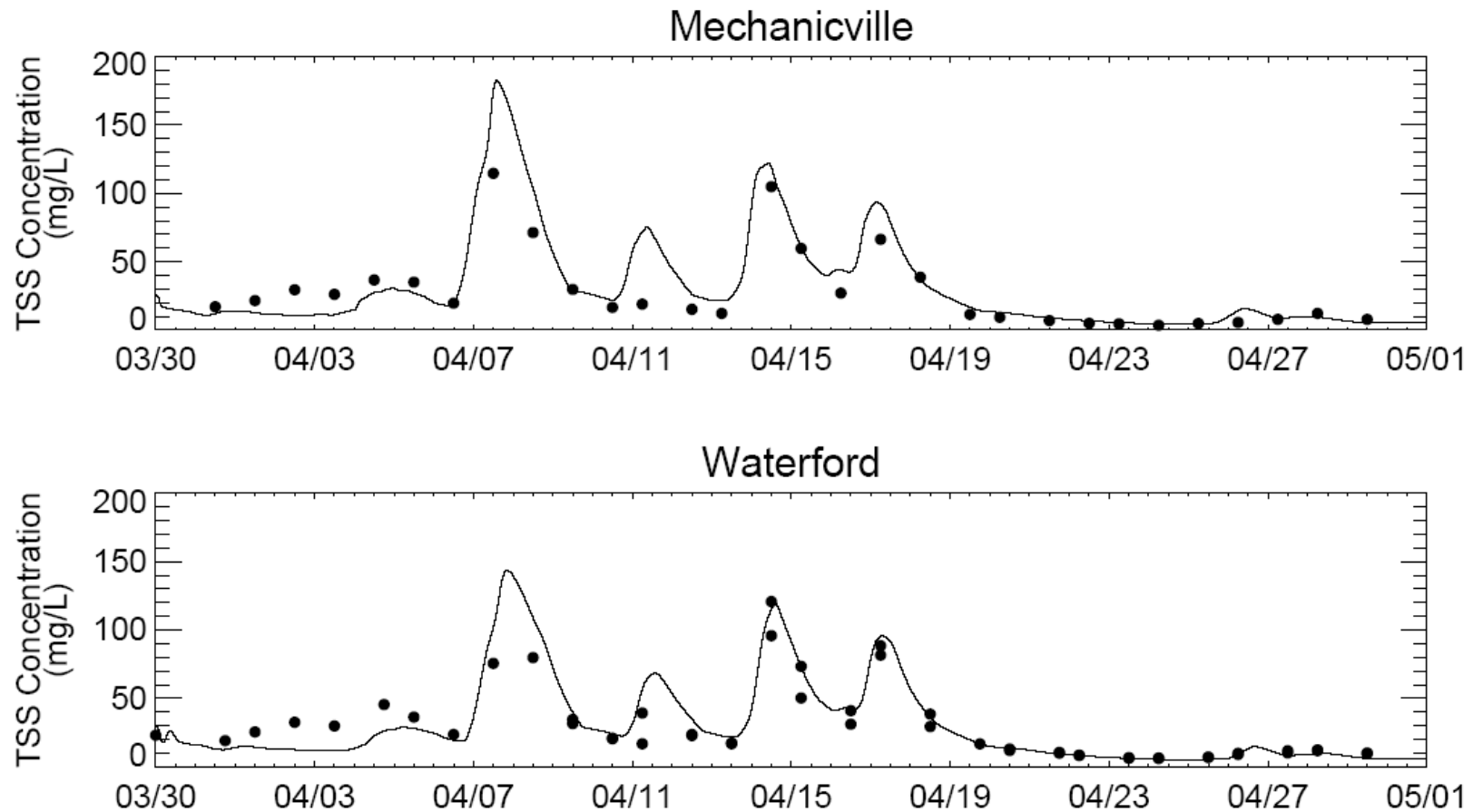
March 30 - April 29, 1994

Sediment Transport Model Calibration: Reach 5



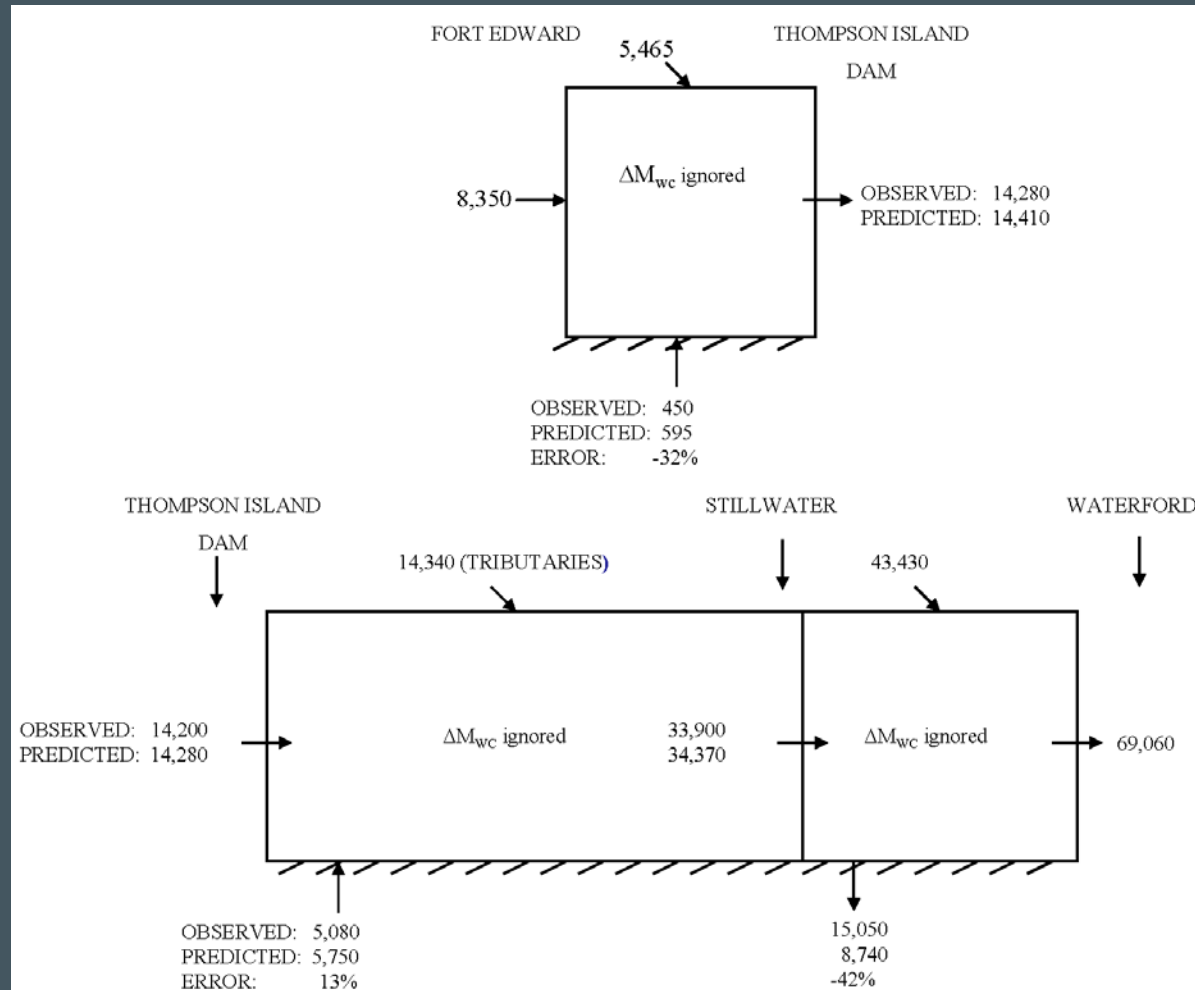
March 30 - April 29, 1994

Sediment Transport Model Calibration: Reaches 1 to 4



March 30 - April 29, 1994

Sediment Transport Model Calibration: Mass Balances for 1994 Flood, Reaches 1 to 8



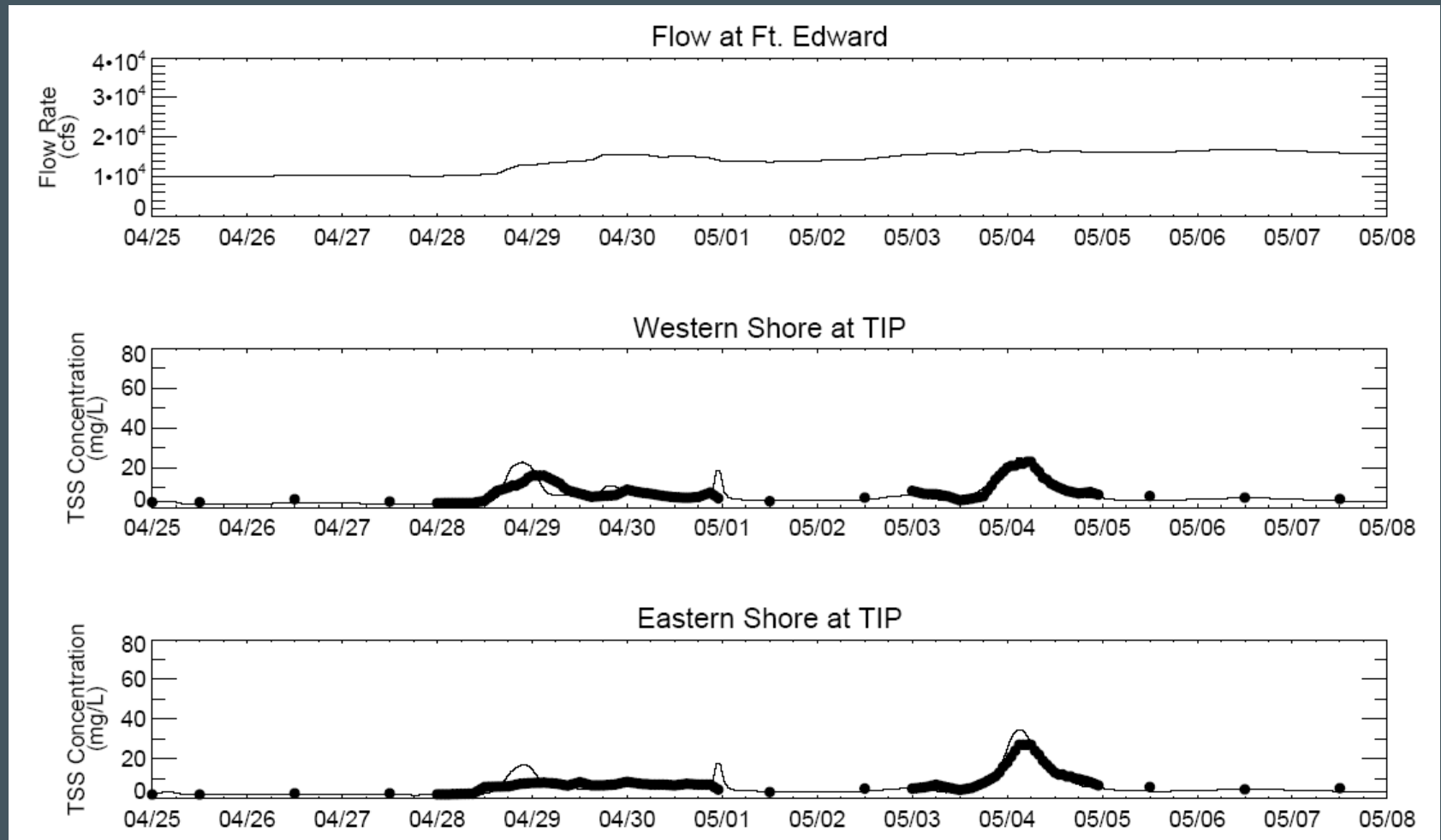
March 30 - April 29, 1994

March 31 - April 29, 1994

Sediment Transport Model Validation

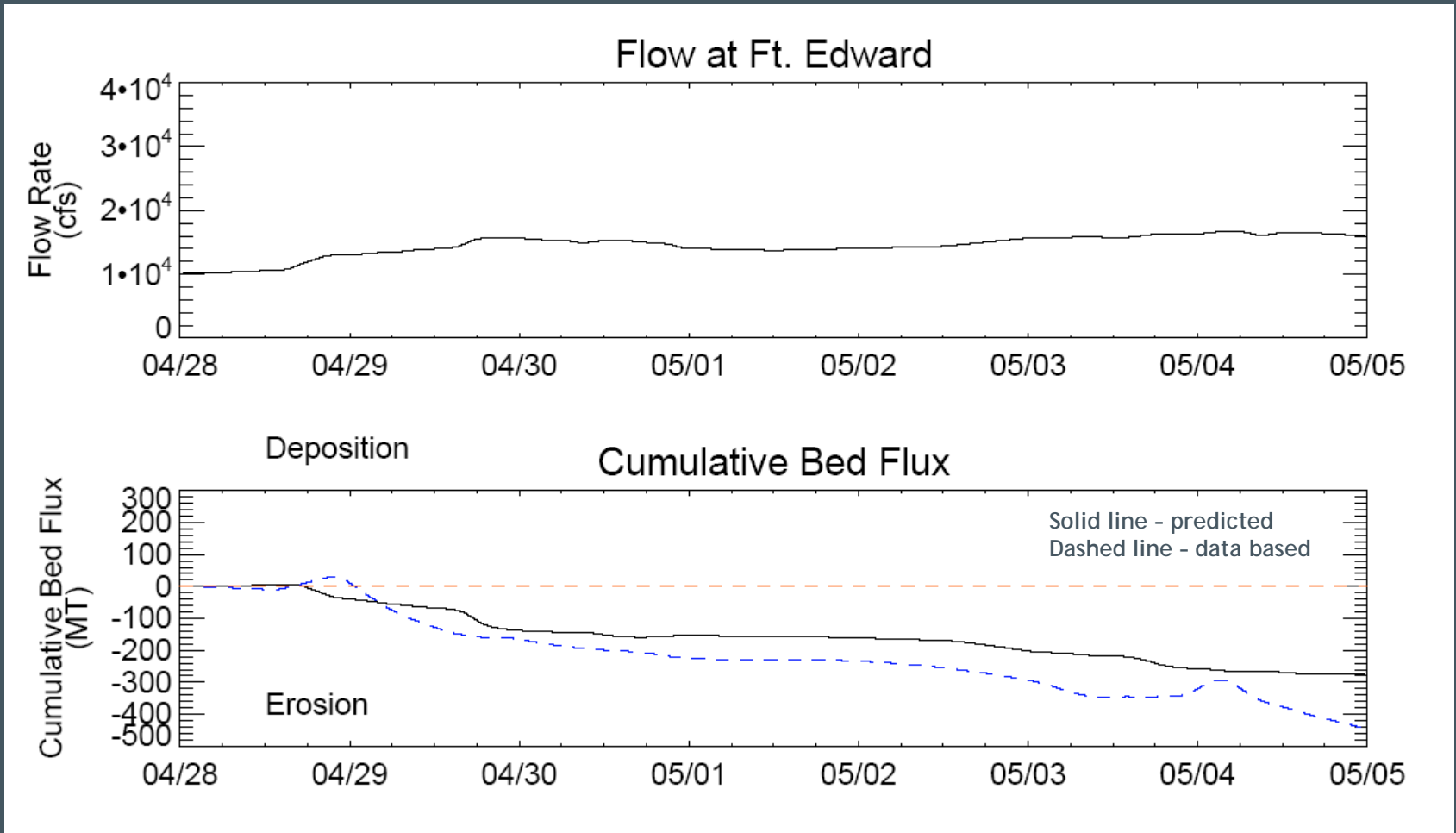
- Used data collected during spring floods in 1993 and 1997
 - TSS concentrations
 - Sediment mass balances
- Initial bed conditions were specified using long-term simulation results
- No adjustment of model parameters during validation simulations

Sediment Transport Model Validation: 1997 Flood



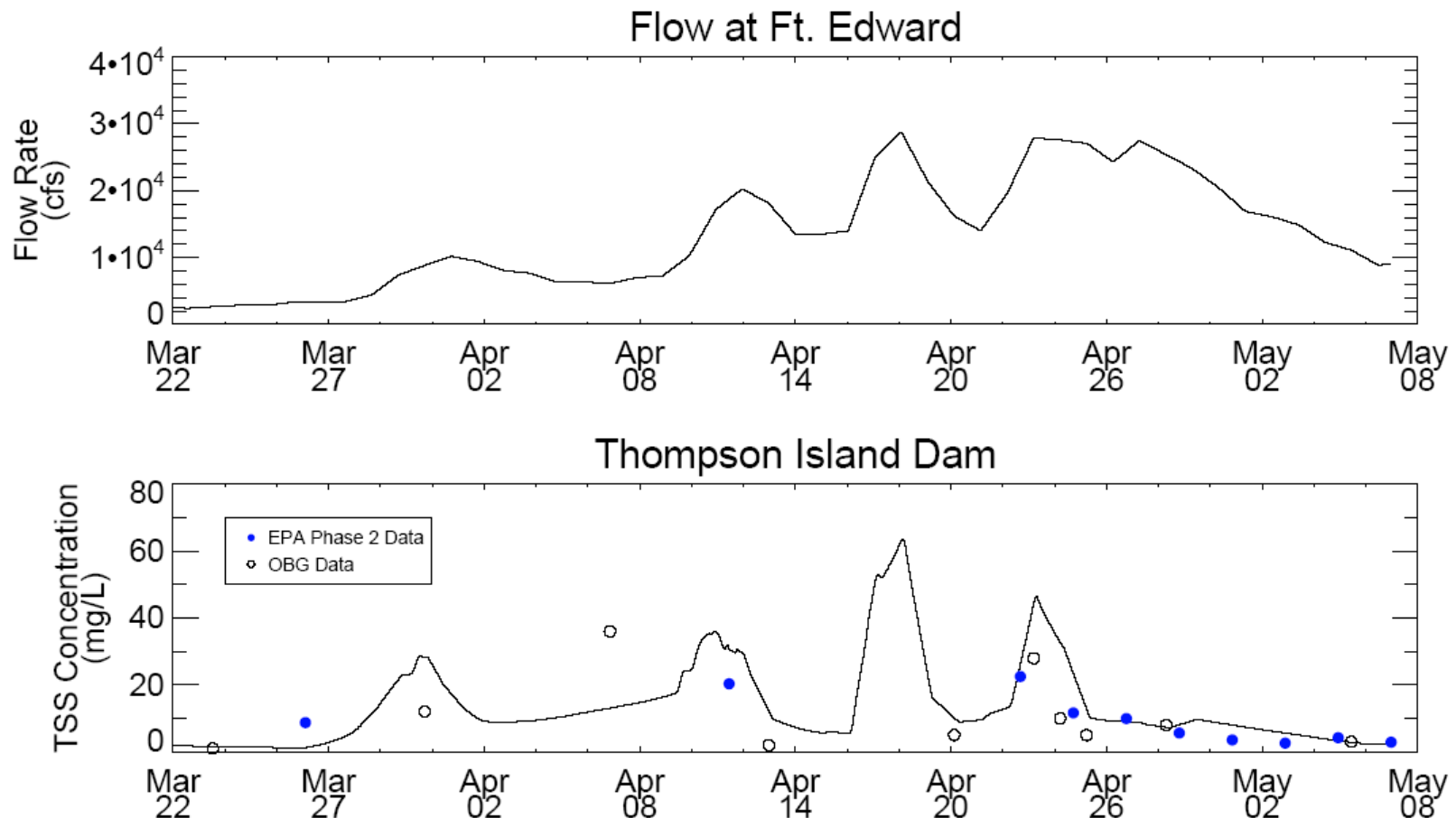
April 28 - May 4, 1997

Sediment Transport Model Validation: 1997 Flood



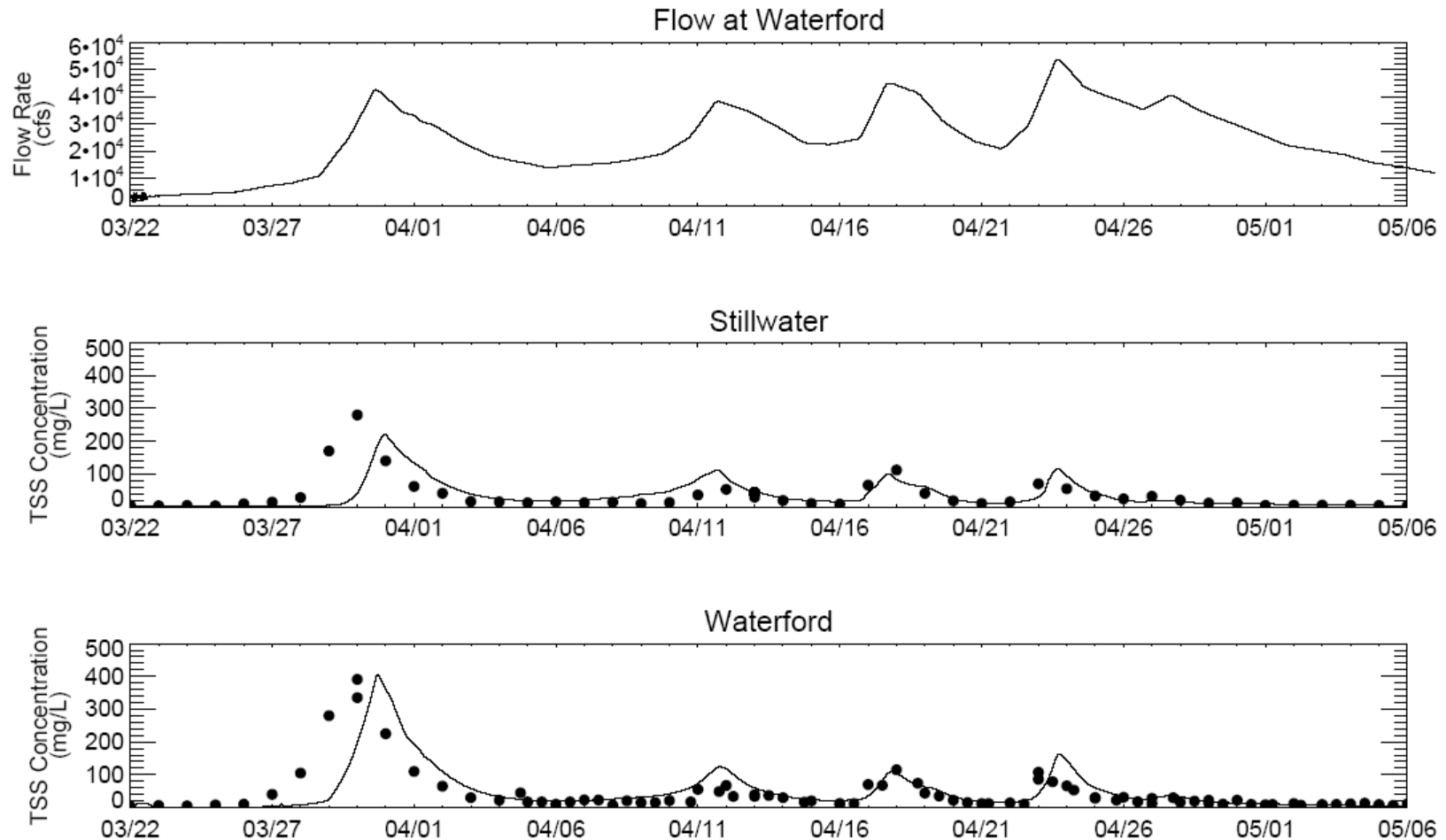
April 28 - May 4, 1997

Sediment Transport Model Validation: 1993 Flood



March 22- May 6, 1993

Sediment Transport Model Validation: 1993 Flood



March 22- May 6, 1993

Sediment Transport Model Summary

- Calibration and validation results demonstrate that the model can reliably simulate sediment transport processes in the UHR
- Suspended sediment concentration, deposition fluxes, and resuspension fluxes (1977 ~ 2010) were transferred to the PCB fate model *via* “coupling files”